



In the Specification

Please delete the text under the heading SUMMARY OF THE INVENTION from column 3, line 43 through column 8, line 45 inclusive.

Please add the following new text under the heading SUMMARY OF THE INVENTION:

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In one aspect of the invention, a method of liquid fuel pressurization and control for a turbogenerator supplied with liquid fuel by a pump disposed in a liquid fuel supply tank comprises the steps of establishing the turbogenerator speed and turbogenerator turbine exhaust temperature required based upon the power load requirements of the turbogenerator, establishing the liquid fuel pressure requirements to produce the established turbogenerator speed and operating temperature, and commanding the pump to produce the established liquid fuel pressure by controlling the torque or speed of the pump in the liquid fuel supply tank.

In another aspect of the invention, a method of liquid fuel pressurization and control for a turbogenerator having liquid fuel supplied to a combustor through a plurality of air assisted liquid fuel injectors comprises the steps of providing a compressor to further compress turbogenerator compressor discharge air, establishing the turbogenerator speed required based upon the power load requirements of the turbogenerator, establishing the air assisted injectors air flow requirements to match the established turbogenerator speed, and commanding the compressor to produce the established

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air flow requirements by controlling the torque or speed of the compressor.

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In yet another aspect of the invention, a method of liquid fuel pressurization and control for a turbogenerator having a combustor with a plurality of air assisted injectors supplied with liquid fuel by a pump disposed in a liquid fuel supply tank and with air assist air by a compressor to further compress turbogenerator compressor discharge air comprises the steps of establishing the turbogenerator speed required based upon the power load requirements of the turbogenerator, establishing the liquid fuel pressure requirements, combustion air flow requirements, and air assist air flow requirements to produce the established turbogenerator speed, and commanding the pump to produce the established liquid fuel pressure requirements and the compressor to produce the established air assist air flow requirements by controlling the torque or speed of the pump and the compressor, respectively.

In a further aspect of the invention, a method for controlling a turbogenerator to provide a required amount of power comprises selecting a turbogenerator speed to produce the required amount of power, selecting a fuel pressure to maintain the required turbogenerator speed, and controlling a fuel pump to provide the selected fuel pressure to a turbogenerator combustor.

Please add the following new text immediately under the heading DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS starting at column 9, line 35:

A2 In the present invention, the liquid fuel pressurization and control system and method utilizes a pump whose speed and shaft torque directly controls the pressure of the liquid fuel delivered to the turbogenerator combustor. This method includes establishing the turbogenerator speed and turbogenerator turbine discharge gas temperature required based upon the power load requirements of the turbogenerator, establishing the liquid fuel pressure requirements to produce the established turbogenerator speed and temperature, and commanding the pump to produce the established liquid fuel pressure by controlling the speed or the torque of the pump.

The liquid fuel pressurization and control system for a turbogenerator includes a pump for supplying pressurized liquid fuel to the liquid fuel injectors of the turbogenerator combustor while the turbogenerator compressor supplies pressurized combustion air to the turbogenerator combustor. A motor, such as a permanent magnet motor, drives the compressor. A compressor motor inverter drive provides electrical power to the motor and receives operational speed and phase data from the motor. The inverter drive also receives torque and maximum speed control signals from the turbogenerator power controller which receives a speed feedback signal from the compressor motor inverter drive. A turbogenerator speed signal and a turbine exhaust gas temperature signal are provided to the turbogenerator power controller from the turbogenerator. A separate compressor can also be utilized to increase the pressure of the turbogenerator compressor discharge air to provide an

air assist to the turbogenerator combustor nozzles and also to cool the liquid fuel. A helical flow compressor and pump can be utilized as the compressor and pump for the liquid fuel pressurization and for the air assist compression.

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A helical flow compressor system is typically thirty (30) to forty (40) times smaller than systems with reciprocating compressors; consumes about one-third ( $1/3$ ) of the energy that other liquid fuel pressurization systems use; does not require the use of an accumulator; does not compress the liquid fuel to a pressure that is higher than is needed and then throw the extra pressure away through valve based flow or pressure regulation; does not cycle on and off; does not operate in a pulsed mode; and is very fast and responsive being controlled by the same computer that controls the entire turbogenerator combustion process.

The helical flow compressor is driven at high speed on the order of twenty four thousand (24,000) rpm by a permanent magnet motor/generator. It is designed to produce very high pressure for a given tip speed of impeller.

A conventional centrifugal pump takes liquid fuel such as diesel oil or gasoline and passes it through an impeller blade which imparts kinetic energy to the liquid fuel. That kinetic energy or velocity energy is converted to pressure energy in a diffuser channel. This happens once each time the liquid fuel goes through the pump. In order to obtain a large pressure

rise, you either have to have a high speed impeller with a large diameter, or you have to have a large number of compression stages.

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A helical flow pump or compressor also takes inlet liquid fuel or air into the impeller blade where it picks up kinetic energy or velocity energy and then the liquid fuel or air goes into a stator channel (which is in effect a vaneless diffuser) where the kinetic energy is turned back into pressure energy. While this happens only once in the typical centrifugal pump or compressor, it typically happens twelve (12) to fifteen (15) times in a helical flow pump or compressor. Thus, you can obtain about twelve (12) to fifteen (15) times as much pressure rise in a single stage of a helical flow pump or compressor as you can obtain in a single stage of a centrifugal pump or compressor.

The helical flow compressor is also designed to produce very low flows whereas the centrifugal compressor requires higher flows for greater efficiency. Because of this, centrifugal compressors operating at high flows have higher efficiencies than helical flow compressors running at their best efficiencies. When, however, you compare centrifugal compressors with helical flow compressors with the same low flows, helical flow compressors actually have higher efficiencies. A centrifugal compressor operating at its best operating condition would be operating at about a seventy eight percent (78%) efficiency. The centrifugal compressor would, however, be operating at its best flow which will be well above

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the flows needed by the turbogenerator. The helical flow compressor operating at its best flow can have efficiencies with curved blades of about fifty five percent (55%) and with straight blades of about thirty eight percent (38%). The efficiency of the helical flow compressor with straight blades for the flows required by the turbogenerator is about twenty five percent (25%) and with curved blades may be slightly over thirty percent (30%). On the other hand, the centrifugal compressor would be under twenty percent (20%) because it would be operating at such a low flow, well below where it is designed to operate at. At these low flows, there is a lot of scroll leakage losses in the centrifugal compressor.

The helical flow compressor has a lightweight wheel or impeller for a given throughput flow rate and pressure rise. The centrifugal compressor will be somewhat heavier with less ability to accelerate and decelerate than the helical flow compressor. If both a centrifugal compressor and a helical flow compressor are both designed to provide what the turbogenerator requires, the impeller of the helical flow compressor would be much lighter and much easier to accelerate and decelerate than the impeller of the centrifugal compressor.

Since the pressure of the liquid fuel introduced into the turbogenerator combustor is a function of the speed of the helical flow pump, the system computer can control the data which controls the motor which controls the pump and effectively has the computer control either the pressure or the flow of the helical

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flow pump which is pressurizing the liquid fuel. In a helical flow pump driven by a permanent magnet motor, or by an induction motor, you can control the torque the motor makes or control the speed or a mix of the two. Typically in this application, the torque is controlled since that controls the pressure rise of the compressor. The buckets have a known cross sectional area at a known radius to the center of the motor shaft. Thus, there is a given pressure rise for a given motor torque. The liquid fuel to the turbogenerator can therefore be effectively controlled.

After ignition, combustion generated turbine torque accelerates the turbogenerator which raises the pressure of the turbogenerator compressor. As the turbogenerator compressor increases the pressure of the combustion air, you will also need to increase the liquid fuel pressure to keep it somewhat higher so that there is a positive flow of liquid fuel to the combustor injectors. If for any reason the turbogenerator gets to a speed so as to produce more turbogenerator compressor discharge pressure than the liquid fuel pressure, the liquid fuel flow will stop and no liquid fuel will enter the turbogenerator combustor and the turbogenerator goes down in speed. This in fact constitutes a speed control mechanism which works extremely well.

A conventional liquid fuel pressurization and control system controls the fuel flow rate delivered to the turbogenerator but not the pressure of the fuel delivered to the turbogenerator. If the flow is held

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constant the turbogenerator speed can run away when the electric power load suddenly drops off. If the electrical load coming out of the turbogenerator drops off, more torque is available from the turbine to accelerate the wheel. The problem is controlling the speed in the system based upon the control of flow of liquid fuel. Only a high speed, high gain servosystem can prevent speed surges if fuel flow is controlled rather than fuel pressure.

In the present invention, the pressure rather than the mass flow of the liquid fuel is controlled and set to a pressure such as of twenty five (25) psi gauge. The turbogenerator will automatically accelerate if the compressor discharge pressure is twenty three (23) psi gauge. At that point, the turbogenerator is getting the amount of fuel it needs to run. With a drop off of load at the turbogenerator, the most that the turbogenerator speed can increase is that change in speed associated with an increase of two (2) psi in compressor discharge pressure. The speed goes up about three percent (3%) or four percent (4%) (considered to be a speed error) and stabilizes out as the gaseous fuel flow naturally drops down. Essentially what the computer based control logic does is reduce this small error by using a limited amount of gain or by using limited authority integration reducing this small error to essentially zero with small variations in fuel pressure. This makes a stable servocontrol.

With prior art technology, there is almost no gain in the turbogenerator by virtue of the fuel fluidics and the compressed air pneumatics, the gain is all in the



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computer that is controlling the liquid fuel and that's a hard thing to do. What is done in the present invention is to use the turbogenerator as a moderate gain servosystem on its own right. If you control the fuel pressure, you control the turbogenerator speed within a five percent (5%) tolerance range for a wide range of output power. The turbogenerator keeps itself from overspeeding and enables the system to get by with a very low gain (thus stable) servosystem that is computer based. Noting the power that the customer wants electrically, the computer goes to look-up tables to determine the speed and temperature at which the turbogenerator should be operating to produce that power. Another look-up table determines what pressure the liquid fuel should have to be consistent with that selected turbogenerator speed and temperature. The fuel pressure is then commanded to be equal to that level by changing the speed of the helical flow pump or by changing the torque of the helical flow pump motor. These conditions are obtained with a very small error because the prediction algorithms can be extremely accurate. A very small authority or limited gain integral proportional controller algorithm can trim out the last errors in speed, exhaust gas temperature, or output power.

A liquid fuel pressurization and control system based on the present invention stabilizes much faster than systems that over pressurize the fuel, then reduce the fuel pressure with a mass flow control valve. It has been demonstrated that this system can control a turbogenerator over a speed range of twenty four thousand (24,000) rpm to ninety six thousand (96,000)

rpm and can control the turbogenerator speed to within ten (10) rpm and that it can also control the turbine exhaust temperature to within two (2) degrees Fahrenheit. It is a very friendly system which does not overshoot and is capable of overcoming many of the difficulties of prior systems.

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In one embodiment, the present invention provides an improved liquid fuel pressurization and control system and method for a turbogenerator.

In another embodiment, the present invention provides a liquid fuel pressurization and control system having means to pressurize liquid fuel to the precise pressure required by a turbogenerator combustor's injection nozzles.

In another embodiment, the present invention provides a liquid fuel pressurization and control system that does not pressurize the liquid fuel to a pressure substantially above that required by a turbogenerator combustor's injection nozzles then subsequently subregulate that pressure down to the level required by the nozzles.

In another embodiment, the present invention provides a liquid fuel pressurization and control system that does not require a mass flow control valve or a pressure control valve to assure that the liquid fuel is pressurized to the precise pressure required by a turbogenerator combustor's injection nozzles.

In another embodiment, the present invention provides

a liquid fuel pressurization and control system that utilizes a variable speed pump to both pressurize the liquid fuel and to control its pressure and flow to precisely match the requirements of the turbogenerator combustor's injection nozzles with no subsequent valve based subregulation.

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In another embodiment, the present invention provides a liquid fuel pressurization and control system that utilizes a variable speed pump having electrical power requirements much lower than those of an automotive fuel pump (owing to pumping only the pressure needed by the turbogenerator rather than overpumping then subregulating) and having this pump submersion mounted in the fuel tank.

In another embodiment, the present invention provides a liquid fuel pressurization and control system having a compressor that does not have output flow rates or output pressures that pulsate.

In another embodiment, the present invention provides a liquid fuel pressurization and control system having a compressor that does not have to be cycled on and off to control the average liquid fuel discharge pressure.

In another embodiment, the present invention provides a liquid fuel pressurization and control system that utilizes either a helical flow pump, or a helical flow pump followed by a gear pump, to pressurize the liquid fuel to precisely the pressure required by a turbogenerator combustor's injection nozzles with no

subsequent valve based subregulation.

In another embodiment, the present invention provides a liquid fuel pressurization and control system that utilizes a pump that is integrated with a drive motor and mounts the rotating pump elements on the same shaft on which is mounted the motor rotor.

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In another embodiment, the present invention provides a liquid fuel pressurization and control system that utilizes a pump motor and motor inverter drive that can be commanded to produce a given motor/pump shaft torque or can be commanded to produce a given shaft speed and in any case will provide a signal that is a function of shaft speed. Note that if the pump motor is a d.c. motor (shunt or otherwise) this objective can be met with interdependent control of motor current and voltage.

In another embodiment, the present invention provides a liquid fuel pressurization and control system that, through fuel control, can control turbogenerator speed to within 10 rpm over an operating speed range of zero to 100,000 rpm and can control turbine exhaust temperature to within 2 degrees Fahrenheit over an operating range of 300 degrees Fahrenheit to 1200 degrees Fahrenheit for the entire output power range.

In another embodiment, the present invention provides a liquid fuel pressurization and control system having means to supply cool air at up to 6 psig above turbogenerator centrifugal compressor discharge pressure to assist atomization of the liquid fuel in

the turbogenerator combustor's air assisted injector nozzles.

A2 In another embodiment, the present invention provides a liquid fuel pressurization and control system utilizing a variable speed compressor to further pressurize some of the air from the turbogenerator centrifugal compressor discharge in order to supply cool air at up to 6 psig above turbogenerator compressor discharge pressure to assist atomization of the liquid fuel in the turbogenerator combustor's air assisted injector nozzles.

In another embodiment, the present invention provides a liquid fuel pressurization and control system utilizing a variable speed helical flow compressor to further pressurize some of the air from the turbogenerator centrifugal compressor discharge in order to supply cool air at up to 6 psig above turbogenerator compressor discharge pressure to assist atomization of the liquid fuel in the turbogenerator combustor's air assisted injector nozzles.

In another embodiment, the present invention provides a liquid fuel pressurization and control system that varies the speed of the helical flow air atomization assist compressor to provide adequate but not excessive air for atomization and adequate but not excessive air for fuel cooling in the injector nozzles (to prevent vapor lock) without utilizing excess electrical motor/inverter power.

In another embodiment, the present invention provides

a liquid fuel pressurization and control system that can reduce the fuel flow through some of the liquid fuel injector nozzles under conditions of low turbogenerator speed and low turbogenerator combustion temperature in order to stabilize the combustion flame, avoid flameouts and reduce the turbogenerator idle speed and idle fuel consumption.

A2 In another embodiment, the present invention provides a liquid fuel pressurization and control system that can reduce the fuel flow through some of the liquid fuel injector nozzles under conditions of low turbogenerator speed and low turbogenerator combustion temperature utilizing solenoid shut-off valves that are sequentially activated for each injector nozzle based on turbogenerator speed and/or turbogenerator turbine exhaust temperature and/or fuel flow rate.

In another embodiment, the present invention provides a liquid fuel pressurization and control system that can reduce the fuel flow through some of the liquid fuel injector nozzles under conditions of low turbogenerator speed and low turbogenerator combustion temperature utilizing a proportional valve or multiple proportional valves that have their flow conductances adjusted as a function of turbogenerator speed and/or turbogenerator turbine exhaust temperature and/or fuel flow rate.

In another embodiment, the present invention provides a liquid fuel pressurization and control system that can reduce the fuel flow through some of the liquid fuel injector nozzles under conditions of low